A Partnership for Modeling the Marine Environment of Puget Sound, Washington

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LONG-TERM GOALS

Puget Sound, Washington, is both the largest fjord in the lower forty-eight states and closest to the substantial urban centers of Seattle, Tacoma, Everett and surrounding communities. The sound has seasonally high annual phytoplankton standing stock and primary production, and they support several economically valuable fisheries. Our long-term goals are to develop quantitative understanding of the Sound's circulation and marine ecosystem, and of the sensitivity of the physical and the biological system to natural and human perturbations; and to develop models of Puget Sound that can aid agencies with responsibilities for environmental management in making informed decisions and serve as marine science education tools.

OBJECTIVES

Our partnership will develop, maintain and operate a suite of flexibly linked simulation models of Puget Sound's circulation and ecosystem, a data management system for archiving and exchanging oceanographic data and model results that are accessible to all members of the partnership as well as to the regional and oceanographic community, and an effective delivery interface for the model results and observational data for research, education and policy formulation. Our partnership will conduct scientific research aimed at developing fundamental understanding of the Sound's working, as well as addressing practical questions raised by the regional community concerning management of the Sound and its resources. Our partnership will function as an estuarine research node within the NOPP Ocean Information Commons.

APPROACH

The partnership consists of five separate organizations: University of Washington (UW, School of Oceanography and College of Education), Department of Natural Resources and Parks, King County, Washington (KC-DNR), Washington State Department of Ecology (WA-DOE), Puget Sound Naval Shipyard (PSNS)/SPAWAR, and Ocean Inquiry Project (OIP). It is administered from School of Oceanography, UW. Collectively we are operating or developing four dynamically based, predictive models of the Sound's aquatic environment, each with a different spatial coverage (and a fifth module for biogeochemistry), and our goal is to integrate these modeling efforts into a coordinated whole. Our tasks are divided as follows:

- Project coordination: Mitsuhiro Kawase (UW)
- Model operation and development:
    - Puget Sound Circulation Model: Kawase, Bruce Nairn (KC-DNR)
    - Sinclair-Dyes Inlet Model: Robert Johnston (SPAWAR), P.F. Wang (SPAWAR)
    - South Puget Sound Model: Jan Newton (WA-DOE), Skip Albertson (WA-DOE)
    - Duwamish Estuary/Elliott Bay Model: Randy Shuman (KC-DNR)
    - Aquatic Biogeochemistry Model (ABC): Allan Devol (UW), Nairn, Newton
- Data management and infrastructure: Miles Logsdon (UW), Mark Warner (UW)
- Education and visualization: William Winn (UW), Fritz Stahr (OIP)

WORK COMPLETED

A project web site (http://www.psmem.org) has been designed and launched in early October 2003. The web site serves as a portal for disseminating results of our model runs and data collected by member institutions, for collaborative interactions among the partners, and for general outreach.

The Partnership's Education and Visualization Team continued to develop and apply model visualizations in educational settings. Improvements were made to Virtual Puget Sound (VPS) (Fig.1). VPS is a dynamic, three-dimensional, interactive visualization of Puget Sound's physical oceanography designed to help students from middle school to undergraduate levels learn about the Sound. It uses data provided from the UW Puget Sound model. The team also developed learning units that fit into existing curriculum for introductory oceanography courses. To assess the effectiveness of these units, new and innovative assessment tools were created to accompany them, and were successfully tested in a community college class in spring 2003.

Partnership members continued their model validation/verification effort through the project period, results of which are summarized in the section below. The UW Puget Sound Circulation Model has been producing one-day hindcasts of the Sound's circulation with forcing from a MM5 regional weather forecasting model. UW and KC-DNR partners have also performed model runs with different resolutions for the Year 2000, during which year they performed an intensive physical oceanographic survey in the northern Main Basin of Puget Sound as part of a siting study for a new marine outfall. Results of these comparisons have been presented as a poster during the 2003 Estuarine Research Conference in Seattle [2].

Virtual Puget Sound Interactive Tools (from left to right)
Measurement panel, salinity cross sections, particle release points, tide chart, legend

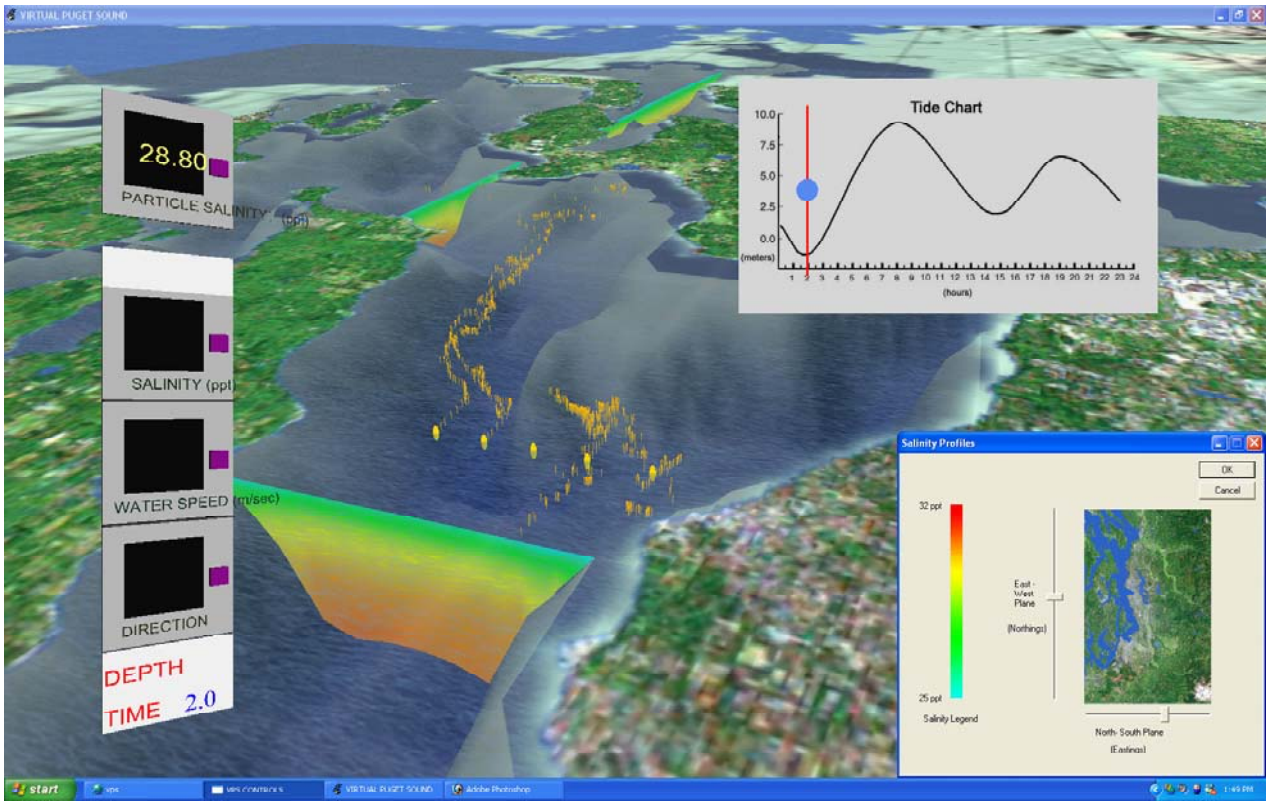

Figure 1. A screenshot of the Virtual Puget Sound showing the central Puget Sound area with simulated surface float trajectories and salt stratification.

The Aquatic Biogeochemistry Model, together with a POM-based circulation model, was implemented for Budd Inlet in South Sound. The combined POM-ABC model has been run for the year 1996-97 for verification against hydrographic and biogeochemical data collected during an intensive survey of the inlet during these years. To aid collaborative development of the ABC model, a collaborative environment was developed in which two off-the-shelf software products, one a Java-based visualizer of netCDF files, the other a threaded discussion, were combined into a forum where people can post quick visualization of model output and make comments.

The PSNS Partners have been developing an Inlet-scale integrated modeling system for Sinclair and Dyes Inlets and the surrounding watershed. Based on the current land use, land cover, and natural and engineered drainage basins, a unified HSPF model for the watershed was developed and linked to the receiving water models. A WASP box model was setup to run long-term simulations, and the kinetic subroutines from WASP were linked directly to a 3-dimensional model (CH3D) to simulate short-term dynamic simulations with finer spatial and temporal resolutions. A Lagrangian particle tracking module within CH3D was used to calibrate the model with data from drogue studies and model dispersion was validated with data from a dye release study. A module to simulate fecal coliform die off was added to the model code and scenarios of combined sewer overflow events were simulated.

The WA-DOE partners collected ADCP data from three inlets in South Puget Sound over the course of the year. Cruises to Case and Carr Inlets and Oakland Bay were conducted over several days with the ship's underway ADCP. These data were compared to the EFDC model output. Albertson presented these results at the Georgia Basin-Puget Sound Conference in April 2003 and a manuscript was prepared for the Proceedings to be published this fall.

RESULTS

Comparison of the Puget Sound circulation model with observational data from Year 2000 has generally allowed us to gain in confidence the model's ability to simulate Puget Sound's circulation. The model had a particular success reproducing the time-average exchange circulation in the Main Basin, as well as recirculation around Vashon Island. In Whidbey Basin, the model and observations had quantitative disagreement with the model showing generally too strong a current, albeit with a correct gross structure. The model also showed a tendency towards insufficient mixing, perhaps due to the mixing parameterization, and underprediction of near-surface temperature.

The coupled POM-ABC model of Budd Inlet has shown that the model is capable of qualitatively reproducing the seasonal cycle of primary production in the inlet. However the circulation time through the inlet (1-2 weeks) is sufficiently short that the open boundary condition dominates the model response to variables with reaction timescales longer than a few days.

The PSNS/SPAWAR partners performed a simulation of the spread of fecal coliform (FC) in the Sinclair/Dyes Inlet system during a November 25, 1998 storm, which resulted in a combined sewage outfall (CSO) event into the inlets. Loading from the streams resulted in a pulse of high FC near the mouths of streams. Discharge from the CSO Event resulted in wider dispersion of the FC plume from the Port Washington Narrows into Dyes and Sinclair Inlets. The total FC loading from the streams was about 1/3 of the total loading from the CSO event.

The WA-DOE partners compared the along-channel Eulerian flows computed from the EFDC South Sound model to shipboard ADCP transects. Agreement of the ADCP data with the model on ebb and flood flow maxima was excellent. Agreement of the ADCP data with the model on residual flow was good, but the model showed a more even distribution of net export at the surface while the data showed great diversity, from normal vertical estuary (Oakland Bay), to a sideways estuary (S Case Inlet), and an inverse estuary (Carr Inlet during summer).

The Education and Visualization team used the Virtual Puget Sound in Spring quarter 2003 in an intensive, three-day introductory oceanography class offered at a community college. On the first and last days of the class, the students worked in the classroom where they and the instructor used VPS and 2D visualizations. The second day was spent on a full-day cruise on a research vessel in Puget Sound where they gathered and interpreted data using a number of tools. This course allowed us to verify that students' understanding of the Sound became more sophisticated after working with VPS. Observation of students on the cruise showed that they were able to make useful connections between what they observed and experienced with VPS and the activities they engaged in at sea. This work was presented at the Estuarine Research Federation (ERF) biannual meeting in Seattle in September 2003 [4].

A comparison of model runs to student-collected data was also presented at the ERF meeting. On a different OIP cruise with University of Washington-Tacoma students we were able to compare model hindcasts to the data collected [5]. The model correctly captured the sense of circulation, including a freshening on the eastern side of Commencement Bay that was observed on the OIP cruise.

IMPACT/APPLICATIONS

National Security

An improved modeling capability of the circulation and marine ecosystem of Puget Sound will help local and regional government devise procedures to deal with, for instance, chemical/biological attacks involving harmful agents that may be/need be flushed down into our marine waters, and with terrorism aimed at military and industrial installations that may result in environmental contamination.

Economic Development

Predictive modeling of Puget Sound's circulation and marine ecosystem will have positive impacts on many economic activities taking place in the Sound. For instance, forecasting of harmful algal blooms (HABs) in the Sound will help shellfish growers better deal with this threat to their livelihood. Detailed knowledge of currents and hydrography will help diving operators with their underwater work. Understanding longer term variability will help managers of fisheries resources make decisions.

Quality of Life

The Puget Sound region has always enjoyed a quality of life directly related to the quality of our environment. Our models provide tools for evaluating the impact of regional scale actions on the marine environment by predicting response of the latter to potential stressors. Oceanographic knowledge also has direct uses and benefits for those who work and live at sea. For instance, knowledge of currents will help Coast Guard and regional law-enforcement agencies with search and rescue operations and contaminant spill containment.

Science Education and Communication

With the aid of suitable visualizations, support material, and curriculum modules, the model results will be a valuable tool for learning about Puget Sound's marine environment that can be used in classroom settings as well as by the public at large in museums and through the web.

TRANSITIONS

Quality of Life

We are partnering with Hood Canal Salmon Enhancement Group (HCSEG), a concerned citizens' group monitoring the aquatic environment of Hood Canal, to address the problem of recurrent fish kills in Southern Hood Canal in recent years. HCSEG has submitted a proposal to National Fish and Wildlife Foundation to monitor and model the oxygen distribution in the canal, with our partnership providing modeling support using the POM circulation model and the ABC biogeochemistry model.

The results of the Inlet-scale model of FC in Sinclair and Dyes Inlets are already being used by the Washington State Department of Health to reclassify shellfish beds in Dyes Inlet [6]. For the first

time since 1969 commercial shellfish harvesting will be conditionally approved for parts of Dyes Inlet [7]. The models will also be used by the Washington State Department of Ecology to establish TMDLs for the Inlets [8].

Science Education and Communication

Poster presentations of the Virtual Puget Sound during the year at the AGU [10] and ERF [4,5] meetings and the Georgia Basin/Puget Sound Research Conference [11] have generated considerable interest in this technology. We have identified a number of groups who are eager to use VPS once it is sufficiently robust to be released more widely. The Ocean Inquiry Project has been funded by the Russell Family Foundation to create and run a *"Strategic Workshop for Coordinating Marine Science Education in Puget Sound"*. Our goal is to increase access to and improve field-based marine science education for all learners in the Puget Sound region through synergistic coordination of existing organizations. It will likely take place in January or February of 2004.

RELATED PROJECTS

The partnership continues a strong cooperative relationship with Puget Sound Regional Synthesis Model (PRISM, www.prism.washington.edu), a University of Washington project to develop and consolidate University-wide expertise in natural and human environment of the Puget Sound region.

The partnership's work compliments work being conducted under PSNS & IMF Project ENVVEST [1] to conduct modeling studies of the Sinclair and Dyes Inlet Watershed to assess the impact of CSO discharges on water quality of the Inlets [9] and support the development of TMDLs for the watershed [3, 8].

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HONORS/AWARDS/PRIZES

Dr. Robert K. Johnston was awarded the Navy Meritorious Civilian Service Award, by the Commander, Space and Naval Warfare Systems Center, on June 11, 2003, in acknowledgement of his outstanding achievements supporting environmental programs at PSNS and Navy Region Northwest.